Larhyss Journal, ISSN 1112-3680, n°62, June 2025, pp. 173-200

ASSESSMENT OF DRY AND WET SPELLS FOR CHANGE IN RAINFALL PATTERN OF THE INDIAN CHHATTISGARH WATERSHED USING THE MARKOV CHAIN APPROACH

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Research Article – Available at http://larhyss.net/ojs/index.php/larhyss/index
Received September 22, 2024, Received in revised form May 26, 2025, Accepted May 28, 2025

ABSTRACT

This study uses a Markov chain technique to predict rainfall patterns in the Indian Chhattisgarh watershed, where rainfall is crucial for agriculture and water resource management. By analyzing historical rainfall data from 1986 to 2021, the study builds a Markov chain model that captures the transition probabilities between different rainfall districts, enabling the prediction of future patterns. The research reveals significant variability in rainfall patterns across the region, emphasizing the unpredictability of rainfall. Notably, the likelihood of a wet day decreases, while the probability of a dry day increases, reaching 60% across all districts. The probability of a dry day consistently exceeds 60% in the crop-growing season, while the chance of a wet day ranges from 30% to 50%. The model also highlights that wet days are more likely to occur after dry days, and vice versa. This Markov chain approach provides a robust framework for understanding and forecasting rainfall patterns. Therefore, stakeholders such as policymakers, farmers, and water resource managers should be empowered to develop proactive drought and flood mitigation strategies.

Keywords: Dry and wet spell, Markov chain, Probability distribution, Rainfall pattern, Chhattisgarh region.

Abbreviation

LASSO	Least absolute shrinkage and selection operator
SMLR	Stepwise multiple linear regression
ANN	Artificial neural network
IMD	Indian Meteorological Department
SNHT	Standard normal homogeneity test

INTRODUCTION

Rainfall is the primary source of water for the agricultural sector in a largely agricultural sector. Studying rainfall is essential for understanding the availability and variability of water resources, predicting floods and droughts, and planning sustainable agricultural and urban development. Rainfall directly influences surface runoff, groundwater recharge, and river flows, making it a key factor in hydrological and climate-related studies. Modeling rainfall enables researchers and decision-makers to simulate future scenarios, improve water management strategies, and mitigate the risks associated with extreme weather events and climate change. Comprehensive insights into these critical aspects are freely readily accessible through the scholarly references listed below, each offering valuable contributions to the current understanding and advancement of the subject matter (Boutebba et al., 2014; Djellouli et al., 2015; Nichane and Khelil, 2015; Gaaloul, 2015; Chibane and Ali-Rahmani, 2015; Faye, 2016; Bemmoussat et al., 2017; Choukrani et al., 2018; Aroua, 2020; Benslimane et al., 2020; Jayasena et al., 2021; Assemian et al., 2021; Nassa et al., 2021; Pandey et al., 2022; Aroua, 2022; Mah et al., 2023; Chadee et al., 2023; Kouloughli and Telli, 2023; Mehta and Yadav, 2024; Atallah et al., 2024; Qureshi et al., 2024; Kezzar and Souar, 2024; Ben Said et al., 2024). Drought occurs when there is either no rain or very little rain. Thus, with increasingly erratic precipitation patterns, the growing season is predicted to shrink (IPCC, 2007; Ray et al., 2018). A dry spell is an extended stretch of dry weather that is less severe than a drought but still quite protracted by usual criteria (Wilhite and Glantz, 1985). The frequency of dry periods has a significant impact on agricultural yields. Decisions about crop selection, water for additional irrigation, and other factors may be informed by data on the duration and frequency of dry periods (Admasu et al., 2014; Houichi, 2017; Patel et al., 2023a). More "light" rainfall spread out over a longer period is preferable to fewer "heavy" showers interspersed with dry spells for crop growth. Dry spells are more important to plant viability instead of total seasonal rainfall when planning a crop schedule (Usman and Reason, 2004). In addition, the amount and pattern of rainfall during a given season are critical for crop productivity, as documented by Simane and Struick (1993). Crops may experience varying degrees of drought due to inconsistent rainfall distribution even though the overall rainfall does not decrease much (Barron et al., 2003; Manikandan et al., 2016).

Arid and semi-arid regions rely primarily on rainfall, therefore understanding its intensity and distribution is crucial to determining the region's agricultural output potential (Kingra et al., 2013; Abdi and Meddi, 2015; Adja et al., 2021; Patel et al., 2023c; Mehta et al., 2024). Furthermore, the quantification of evapotranspiration from agricultural areas is important for agriculture water management, especially in these regions where water deficiency is becoming a major constraint in economic welfare and sustainable development (Remini, 2010; Hamimed et al., 2017; Soro et al., 2018). On the other hand, groundwater serves as the most reliable source of water both for domestic use and for irrigation in these zones, which are characterized by low rainfall and high evaporation. To address the persistent challenge of water scarcity in these regions, several context-specific and practical solutions have been proposed, including the use of traditional water management systems—locally developed and adapted to environmental constraints—as well as modern technological interventions such as desalination processes, which provide an alternative source of freshwater, particularly in coastal and arid zones (Remini, 2020; Derdour et al., 2022; Remini and Amitouche, 2023a). However, it has been strongly recommended that a comprehensive study be conducted to assess the potential environmental impacts of the desalination plant on the surrounding marine ecosystem, including effects on water quality, marine biodiversity, and coastal hydrodynamics (Belkacem et al., 2017; Amitouche et al., 2017; Remini and Amitouche, 2023b).

Chhattisgarh experiences extreme rainfall variability because of the unpredictable behavior of the monsoon during the kharif season along with western disturbances during the rabi season. Large areas of the state have been devoted to growing paddy and wheat during the kharif and rabi seasons, respectively, and their high-water demands have exacerbated the state's already severe water shortage. The duration and extent of the humid period is an important factor in agricultural growth and planning. The amount of rainfall that falls during growing seasons is a major factor in many agricultural activities. Rainfall intensity and duration influence runoff and soil erosion, factors that are significant in agricultural land management. Heavy rainfall events can lead to soil degradation, affecting agricultural productivity (Riahi et al., 2020). The advancement of agricultural activities necessitates long-term projections of climate variability, along with anticipated changes in rainfall patterns that may significantly influence planning and resource management (Oga et al., 2016; Smadhi et al., 2021; Ouattara et al., 2022). Therefore, improved crop planning is possible with the knowledge and database of both wet and dry spell patterns of a certain region. For effective crop planning, development of appropriate agro-technology, selection of appropriate crops, and construction of soil conservation structures (Niang et al., 2015), the probability analysis of the likelihood of wet and dry spells is vital (Singh et al., 2008; Douh et al., 2013; Patel et al., 2023b). Consequently, the analysis of dry and wet periods helps determine the likelihood of intraseasonal drought so that management can be adapted accordingly (Kumar and Rao, 2005; Benzougagh et al., 2022; Mehta et al., 2023).

The long-term occurrence of both dry and wet spells has been studied extensively by employing the Markov chain probability model (Victor and Sastry, 1979). Markov chain models have long proven to be highly effective tools for addressing a wide range of hydrological challenges. Several studies have successfully applied Markov chains, particularly for the analysis of precipitation patterns and the assessment of drought persistence (Lazri et al., 2007). Moreover, the examination of spatial and temporal variability continues to serve as a fundamental approach for water resource managers seeking to understand and predict fluctuations in water availability (Zeggane et al., 2021). In addition, the weekly rainfall probability for Ludhiana was also calculated by Goyal et al. (2015) using this method and an inadequate gamma distribution. Both the initial and conditional probability at several periods for rainfall have been analyzed weekly. By incorporating this data into agricultural planning, farmers will be able to make better use of available water resources, including rainwater and groundwater, and boost crop yields. If the dry period occurs when the crop needs the most moisture, it will cause harm, but if it occurs when the crop is maturing, it could be helpful. However, if the wet period coincides with the stages of the crop where the greatest moisture is needed, it will be beneficial for improving productivity while still preserving groundwater.

This study looks into both dry and wet weather patterns in the Chhattisgarh region by employing a popular method called Markov chains. After the findings of Gabriel and Neumann (1962), the use of Markov chains to describe daily rainfall events became significant traction. Subsequently, numerous research examines the potential of the Markov chain to model rainfall patterns (Dahale et al., 1994). Additionally, several researchers have produced probability models to characterize the rainfall distribution pattern, which may be used to evaluate the frequency of dry and wet periods (Manning, 1950; Feyerherm and Bark, 1967; Kulandaivelu, 1984; Phien and Ajirajah, 1984; Benkaci et al., 2020; Topalogu, 2002; Bong et al., 2023).

Piyadasa and Sonnadara (2010) used Markov chains using 51 years of daily rainfall data to study the weekly climatology of the dry zone. They found that there was no discernible difference between the first as well as second-order models in terms of rainfall pattern and intensity. Precipitation incidence in Sri Lanka's wet and dry zones was predicted utilizing Markov chains in a study conducted by Perera et al., (2002). They determined that, for both humid and arid regions, the second-order model offered no noticeable improvements over the first. A similar finding was reached in a subsequent study (Piyadasa and Sonnadara, 2010) that used Markov chains to predict the occurrence of rainfall based on long-term daily rainfall observations. This study also provided conclusive results regarding the accuracy and reliability of Markov models in modeling wet and dry spells, suggesting that this is an interesting area of additional research.

Satpathi et al., (2023) suggested that predicting crop yields before harvest is crucial for shaping, executing, and enhancing food safety policies and for managing agricultural product storage and marketing. Weather conditions have a significant impact on crop growth, making models that incorporate weather variables a reliable method of forecasting crop yields. Selecting the most suitable crop yield forecasting model can be a challenging task. Five models are compared in this study. They are ridge regression, least absolute shrinkage and selection operator (LASSO), stepwise multiple linear regression (SMLR), and artificial neural network (ANN). The objective is to identify the most effective model for predicting rice yields. Subsequently, a research study conducted by Jaiswal et al., (2023) in the Mahanadi River Basin of India focused on assessing the irrigation requirements for Kharif paddy cultivation by examining seasonal rainfall patterns and extreme weather events. The study utilized data collected from 206 weather stations, spanning the period from 1981 to 2015. Given the challenges posed by low rainfall and frequent extreme weather events, it was observed that the upper basin of the Mahanadi watershed, specifically Chhattisgarh, had a higher demand for water resources to support paddy cultivation. To establish a connection between rainfall, severity indices, and the irrigation needs of Kharif paddy, a robust multi-linear regression model was developed. This model demonstrated excellent performance during both the calibration and validation phases, as indicated by high Nash-Sutcliffe efficiency scores of 0.82 and 0.89, respectively. The successful implementation of this model holds promise for effective water resource planning in the region. Moreover, this approach can serve as a template for developing similar models tailored to the irrigation requirements of other crops by identifying relevant severity indicators.

IMPORTANCE OF THE PRESENT STUDY

The assessment of dry and wet spells and changes in rainfall patterns in the India Chhattisgarh watershed, using the Markov chain approach is crucial for agriculture, water management, climate adaptation, disaster preparedness, economic stability, environmental conservation, policy development, and community resilience. Understanding rainfall distribution supports climate-resilient farming, efficient water allocation, and adaptation planning. It enhances disaster preparedness, mitigates economic risks, and informs conservation strategies. Accurate data aids evidence-based policymaking in agriculture, water resources, and disaster management. Ultimately, this research strengthens community resilience by enabling informed decisions on farming, water storage, and disaster response, fostering sustainable development amid changing climate patterns. Therefore, the primary objective of this study was to analyze daily rainfall patterns using the Markov chain to better understand the wet and dry weather variations. The performance of the first-order model in different areas was analyzed, the frequency of wet and dry cycles, and its changes. As a result, the purpose of the present study is to examine the length of dry spells and their effects on agricultural output in the different regions of Chhattisgarh. Thus, the farmers in the area can better prepare for droughts and reduce the amount of unanticipated damage that occurs.

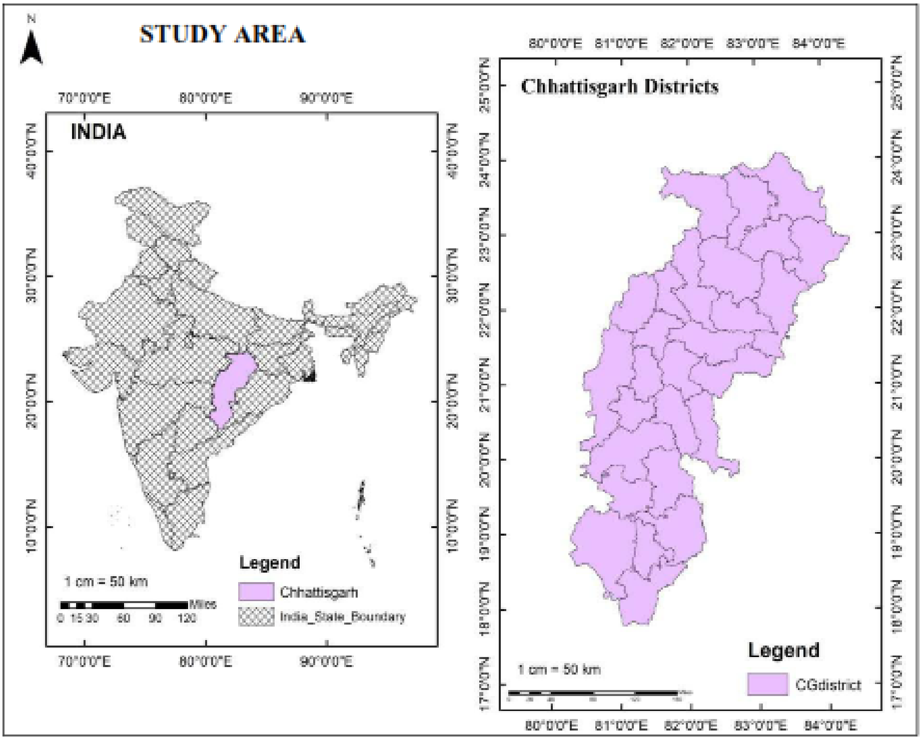


Figure 1: A map showing the location of Chhattisgarh region

MATERIAL AND METHODS

Study Area

This study focuses on the examination of rainfall data from the study area of Chhattisgarh, which is located at coordinates 21.2787° N, and 81.8661° E. The data spans 36 years, from 1986 to 2021. To ease analysis, the study region of Chhattisgarh has been divided into 27 districts, as shown in Fig. 1. Mean rainfall figures have been computed for each district, offering insight into the average precipitation experienced in specific areas of Chhattisgarh. Furthermore, the average annual rainfall for the entire study region of Chhattisgarh is projected to be 1,255.1 mm/year (Sahu et al. 2022a; Sahu et al. 2022b; Tandel et al., 2023; Verma et al. 2021; Sahu et al. 2023c; Azharuddin et al. 2022; Sahu et al. 2021b; Dhiwar et al. 2022; Verma et al. 2023a; Verma et al. 2022a; Verma et al. 2022c; Verma et al., 2023d; Pradhan et al., 2022; Sahu et al. 2021a). This metric is a useful indicator for assessing the meteorological conditions in Chhattisgarh across the time studied.

Data Used

The research entails gathering daily gridded rainfall data from all districts in Chhattisgarh. In the present study, there are 189 gridded stations. Grid-based rainfall data covering the entirety of Chhattisgarh over 36 years (1986–2021) may be acquired from the Indian Meteorological Department (IMD) in Pune, India. (Verma et al. 2022f; Verma et al. 2022g; Verma et al. 2022d; Sahu et al. 2022c; Sahu et al. 2022d; Verma et al. 2022e; Verma et al., 2023c). This sophisticated application enables efficient manipulation and study of the obtained rainfall data. Formulations and conditional statements in Microsoft Excel are used to accomplish various calculations and analyses. The Markov chain model, which is built into R-Studio, is critical to the study's research and findings. The study offers a full analysis of the rainfall data by combining the capabilities of Microsoft Excel and R-Studio, allowing the researchers to acquire significant insights into the patterns and dynamics of rainfall in Chhattisgarh. Additionally, using the Markov property, the Markov Chain model analyzes and models the probability changes between states. The methods mentioned above typically involve estimating the stationary distribution of the Markov Chain, estimating the transition probabilities between states, and identifying the probability of the initial states (Fig. 2).

Consistency/homogeneity test

A consistency test is conducted to assess whether the behavior of the mechanism generating a portion of time series data aligns with that specific segment of the time series. To perform this test, we employ a standard normal homogeneity test (SNHT) utilizing an XLSTAT plug-in package within MS Excel. When considering a 5% significance level, if the calculated p-value is greater than 0.05, we conclude that the station is consistent.

Stationarity test

Stationarity is a statistical property of time series data, meaning that it remains unchanged across different samples, except for variations due to sampling. In practical terms, this definition of stationarity focuses on the constancy of two key attributes: the mean (expected value) and the variance. A time series that maintains a consistent mean is termed a first-order stationary series, while one that exhibits constancy in both covariance and mean is referred to as a second-order stationary or 'weakly stationary' series (as covariance stationarity implies variance stationarity). If additional statistical properties also remain invariant over time, the series is classified as' strongly stationary.' It's important to note that a process can exhibit stationarity in one property while lacking it in others. Conversely, a time series characterized by varying statistical properties over time is known as a non-stationary time series, often containing deterministic components such as trends and periodic patterns.

Necessity of assumption for stationarity

The following assumptions have been adopted during the present study:

- Standard techniques are largely invalid where data is non-stationary.
- Autocorrelation is a possible outcome when a time series is non-stationary.
- Nonstationary time series regression may also result in spurious regression, i.e., cases when the regression equation shows a significant relationship between two variables when there should not be any such relation.

Tests for checking stationarity

A stationary test is performed to identify whether the sequence generated by time series data is weather stationary or non-stationary. For testing the stationarity of time series data, we have to use two different methods, which will be discussed below.

Dickey-fuller test

In statistics, the Dickey–Fuller test is performed to identify whether the generated time series data is stationary or trend stationary. For this test, we have to use the XLSTAT package plug-in in MS Excel. For the 5 % significance level, when $P < 0.50$, then the station becomes stationary, otherwise it is considered non-stationary.

Phillips-Perron test

In statistics, the Phillips-Perron test is performed to identify whether the generated time series data is stationary or trend–stationary. For this test, we have to use the XLSTAT package plugin MS-Excel. For the 5 % significance level, when $P < 0.50$, then the station becomes stationary, otherwise it is considered as non-stationary.

Markov Chain Probability Analysis

The Markov Chain Probability Model is used to examine dry and wet spells as they relate to rainfall patterns. This model examines the probability associated with consecutive dry or rainy days over a specified time, such as the crop growing season. By researching these probabilities, useful insights into the incidence and duration of dry and wet spells can be gleaned, assisting in crop planning and agricultural decision-making. The Markov Chain Probability Model gives a systematic approach to understanding the dynamics of dry and wet spells, improving the ability to manage and respond to changing rainfall circumstances. Crop success in rainfed areas is highly dependent on rainfall patterns. It is critical for crop planning to analyze rainfall data and determine the probability of sequential events, such as consecutive rainy or dry days during the crop growing season. A rainfall threshold of 2.5 mm per day has been found appropriate for crop growth across all growth stages of the crops produced. As a result, any day with less than 2.5 mm of rainfall is classified as a dry day, whereas any day with 2.5 mm or more of rainfall is classified as a wet day. Using this criterion, each day is classified as either dry or wet, and the corresponding probability is determined.

This method allows for a better understanding of rainfall patterns and their impact on crop growth, allowing for more informed crop planning and agricultural activities, such as protective irrigation. The study attempts to improve the efficiency and efficacy of agricultural practices in response to rainfall variability by utilizing the Markov-Chain process and taking into account the specific threshold for dry and wet days.

A Markov chain of order n implies that the prior n states have an impact on the likelihood of moving to a different state. When applied to the modelling of wet and dry weather patterns, these states would signify whether the weather is wet or dry during a specific time interval. In a first-order Markov chain (n = 1), the transition to a new state relies solely on the current state, making it suitable for certain time series data but less effective at capturing the memory or persistence often observed in weather patterns. Weather conditions often exhibit short-term persistence, meaning that if it's wet today, there's a higher likelihood of it being wet tomorrow, and vice versa. On the other hand, a second-order Markov chain (n = 2) considers not only the current state but also the preceding state when determining the probability of transitioning to a new state. This added level of memory enables the model to better capture short-term persistence. It is more adept at representing scenarios where wet or dry conditions tend to persist for a day or two before changing.

Initial probability of dry and wet days

For classifying dry and wet days, the following probabilities can be calculated by using Eq. (1) and Eq. (2), respectively.

$$P(D) = F(D) / N \tag{1}$$

$$P(W) = F(W) / N \tag{2}$$

where: P(D): indicates the probability of a dry day, P(W): represents the probability of a wet day, FD: represents the number of dry days, FW: represents the number of wet days, and N is the number of days of available data.

Based on historical patterns, these estimates provide useful insights into the likelihood of encountering dry or wet days. Agricultural planners and academics can make informed decisions and build strategies by estimating the initial probabilities.

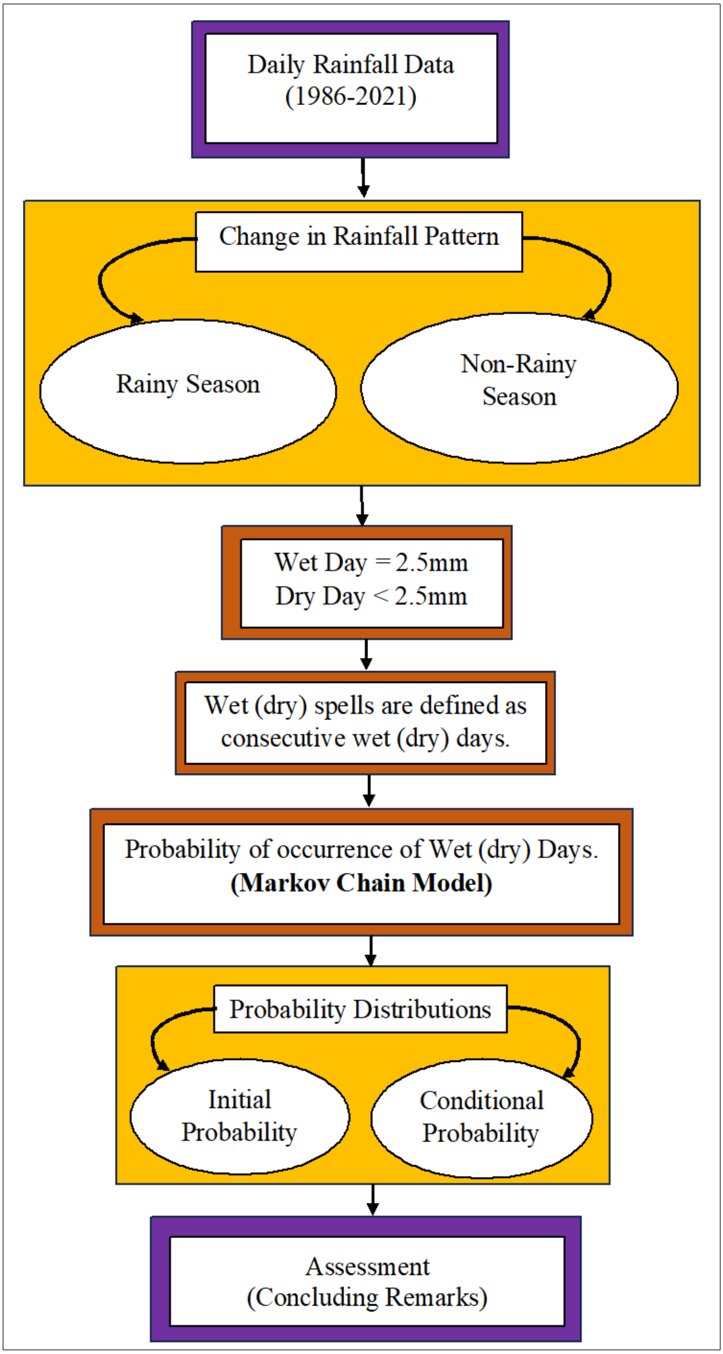


Figure 2: Flow diagram displaying an extensive process.

Conditional probability of dry and wet days

The following calculations can be used to further analyze the conditional probabilities of dry and wet days which are presented in Eqs. (3) to (6).

$$F(DD) / F(D) = P(D/D) \quad (3)$$

$$F(WW) / F(W) = P(W/W) \quad (4)$$

$$P(W/D) = 1 - P(D/D) \quad (5)$$

$$P(D/W) = 1 - P(W/W) \quad (6)$$

where: P(D/D): denotes the likelihood of a dry day being preceded by another dry day, P(W/W): denotes the likelihood of a rainy day being preceded by another wet day, P(W/D): denotes the likelihood of a wet day being preceded by a dry day, P(D/W): denotes the likelihood of a dry day being preceded by a wet day, F(DD): is the number of dry days followed by another dry day, F(WW): is the number of rainy days preceding another wet day, The total number of dry days is represented by F(D), The total number of wet days is represented by F(W).

These conditional probabilities provide insight into the transitional probabilities between dry and rainy days, allowing for a more comprehensive knowledge of rainfall patterns. Agricultural planners can make better decisions about crop management, irrigation techniques, and other agricultural activities by factoring in the likelihood of consecutive dry or wet days.

Markov chain model

Markov chain models are mathematical frameworks used to examine the onset and likelihood of occurrences that display some degree of unpredictability or dependence on prior events. In this model, the alternating wet and dry periods are represented as a sequence of states, where each state represents either a wet or dry period. The likelihood of changing states is conditional solely based on the current state and not on past events. The Markov property describes this presumption.

The likelihood of a dry period following a rainy period or vice versa is estimated by the model by analyzing historical data such as rainfall records. Understanding the typical length of dry and wet periods, as well as the frequency of their changes, might be aided by these probabilities.

The model aids in understanding transitions between rainfall states, such as dry and wet spells, in the context of rainfall analysis. Transition probabilities are used to represent the possibility of changing states. This probability can be determined by analyzing past data and providing insights into specific rainfall patterns. This data is useful for applications such as crop planning and water resource allocation since it helps comprehend the probability associated with various rainfall scenarios. The following relationships are derived from the model:

$$P(Wi) = 1 - P(Di) \tag{7}$$

$$P(Di/Di\text{-}1) - P(Wi/Di\text{-}1) \tag{8}$$

$$P(Di/Wi\text{-}1) = P(Di) - P(Di\text{-}1)x\ P(Di/Di\text{-}1) \tag{9}$$

$$P(Di/Wi\text{-}1) - P(Wi/Wi\text{-}1) = 1 \tag{10}$$

where: P(Di/Wi-1): denotes the likelihood that the i^{th} day will be dry if the $(i\text{-}1)^{th}$ day was wet. These relationships can be used to derive other definitions. Notably, from the original data, just the initial likelihood of the i^{th} day in a year being dry, P (Di), and the transition probability of the i^{th} day being dry when the previous day is dry, P (Di/Di-1), must be determined.

RESULTS AND DISCUSSION

Data Quality Check

The daily gridded precipitation data have been collected from the Indian Meteorological Department (IMD) in Pune, India, for 36 years from 1986-2021. The consistency test is used to assess whether the behavior of the process that produces a section of time series data is taken into account. The standard normal homogeneity test (SNHT) is used for this reason, and the grid location is considered compatible if the p-value is > 0.05. The locations having a p-value less than 0.5 have been discarded (highlighted) for further analysis (Table 1).

Table 1: List of rainfall stations and their locations over the study area

Districts	Location	p-value	Districts	Location	p-value
Koriya	(23.25°N 82.55°E)	0.210	Bemetara	(21.70°N 81.53°E)	0.132
Surajpur	(23.22°N 82.85°E)	0.140	Rajnandgaon	(21.10°N 81.03°E)	0.230
Balrampur	(23.60°N 83.61°E)	0.210	Durg	(21.19°N 81.28°E)	0.942
Jashpur	(22°54′N 84°09°E)	0.413	Balod	(20.73°N 81.2°E)	0.344
Surguja	(23.22°N 82.85°E)	0.341	Dhamtari	(20.71°N 81.55°E)	0.846
Raigarh	(21.8°N 83.3°E)	0.201	Gariyaband	(20°36N 82°06″E)	0.540
Korba	(22.35°N 82.68°E)	0.204	Kanker	(20.27°N 81.49°E)	0.402
Bilaspur	(22.09°N 82.15°E)	0.347	Kondagaon	(19.6°N 81.67°E)	0.301
Mungeli	(22.07°N 81.68°E)	0.468	Narayanpur	(19.71°N 81.25°E)	0.448
Kabirdham	(22.02°N 81.25°E)	0.581	Bijapur	(18.79°N 81.80°E)	0.445

Janjgirh Champa	(22.01°N 82.56°E)	0.271	Dantewada	(18.90°N 81.33°E)	0.412
Balodabazar	(21.67°N 82.17°E)	0.634	Bastar	(19.18°N 81.9°E)	0.537
Mahasamund	(21.11°N 82.10°E)	0.482	Sukma	(18.40°N 81.66°E)	0.456
Raipur	(20°55′N 82°00′E)	0.846			

Annual Rainfall Variation

In this section, the rainfall patterns throughout different regions are highlighted, along with an examination of their potential consequences. Bijapur, Bastar, and Sukma are the rainiest districts, as stated in Table 2. These regions regularly experience high levels of precipitation and are therefore classified as flood zones. Because of this, they likely experience heavy precipitation, which could cause floods in the future. Annual precipitation is lower in Kawardha, Balodabazar, and Raipur despite their high individual precipitation totals. These areas don't get flooded as often as more flood-prone locations, but they nevertheless get rain frequently. However, the statement indicates that these areas are more susceptible to drought since they receive less annual rainfall. This suggests that the amount of rain these areas get might not be enough to stave off drought, even though the frequency of rainstorms is high. The capital of Chhattisgarh, Raipur, is home to a large and quickly growing population. Because of urbanization and the consequent changes in land use and infrastructure, this area is at increased risk of flooding. The text claims that the combination of urbanization and high population growth increases the risk of floods in Raipur, even though the city receives less annual precipitation accumulation.

In conclusion, Table 2 shows how the districts of Chhattisgarh experience rain in a variety of ways. The districts of Bijapur, Bastar, and Sukma, among others, receive an excessive amount of rainfall, making them vulnerable to flooding. Other places are more at risk of drought because of low annual rainfall accumulation, such as Kawardha, Balodabazar, and Raipur. In addition, the text argues that the urbanization and high population density of Raipur contribute to its being subject to flooding situations even though it receives less annual rainfall. The yearly rainfall variance in each district is listed in Table 2.

Seasonal Rainfall Variations

The maximum seasonal rainfall in Chhattisgarh districts fluctuates from year to year, contingent upon monsoon patterns and other atmospheric variables. Chhattisgarh generally encounters a monsoon climate, characterized by a rainy season that spans from June to September. Among the districts in Chhattisgarh, those situated in the eastern and southern regions of the state, nearer to the Bay of Bengal, typically record the most substantial monsoon rainfall. Several districts in these areas exhibit comparatively elevated levels of both annual and seasonal rainfall.

Bastar district, situated in the southern region of Chhattisgarh, typically witnesses substantial rainfall (1417.281mm) during the monsoon season. Similarly, the Dantewada district also encounters significant rainfall (1462.113mm) during this period. In addition, moving southward, Bijapur district in southern Chhattisgarh is renowned for its abundant rainfall (1518.279mm) during the monsoon season. Likewise, Sukma district, along with other southern districts, receives a noteworthy amount of rainfall (1474.303mm) during this season. In the eastern part of Chhattisgarh, Korba district frequently enjoys a substantial volume of rainfall (1287.838mm) (Table 3).

Table 2: Distributional patterns of rainfall in various regions of Chhattisgarh

Years	Districts	Maximum Rainfall (mm)	Minimum Rainfall (mm)
1986	Narayanpur	1612.400	1036.750
1987	Jashpur	1400.900	751.567
1988	Korba	2718.830	601.400
1989	Bijapur	1969.392	870.273
1990	Bijapur	2201.758	1175.709
1991	Sarguja	1637.320	738.950
1992	Bijapur	1508.950	790.267
1993	Dantewada	1520.640	935.817
1994	Bijapur	2244.367	1246.450
1995	Bijapur	1719.833	781.283
1996	Bijapur	1619.967	640.175
1997	Jashpur	1541.420	1004.117
1998	Jashpur	1874.260	719.633
1999	Bijapur	1917.542	733.150
2000	Bijapur	1530.283	488.850
2001	Kanker	1996.433	1177.375
2002	Raigarh	1473.809	735.450
2003	Bijapur	1883.392	1302.645
2004	Dantewada	1461.620	765.733
2005	Kanker	1440.700	982.727
2006	Sukma	2459.417	741.933
2007	Dantewada	1783.900	852.833
2008	Dhamtari	1630.150	822.600
2009	Mahasamund	1395.317	669.986
2010	Bastar	2086.571	496.743
2011	Koriya	1746.964	899.833
2012	Sukma	1935.350	961.117
2013	Bijapur	1876.225	823.300
2014	Mahasamund	1717.150	816.764
2015	Sukma	1815.800	724.682
2016	Durg	1803.925	879.383
2017	Sukma	1808.950	709.350
2018	Sukma	2668.067	755.628
2019	Bastar	2018.260	986.736
2020	Bijapur	2079.149	1063.424
2021	Mungeli	1531.565	918.211

Table 3: Seasonal rainfall pattern in various regions of Chhattisgarh from 1986-2021

Districts	Rainfall Accumulation for Rainy Season MJJASO (mm/year)	Rainfall Accumulation 2for Non-rainy Season NDJFMA (mm/year)
Koriya	1138.795	56.782
Surajpur	1134.727	66.283
Balrampur	1100.179	56.084
Jashpur	1308.153	79.571
Surguja	1254.066	73.195
Raigarh	1255.264	66.007
Korba	1287.838	62.046
Bilaspur	1163.1	65.687
Mungeli	1131.818	75.821
Kabirdham	1031.666	63.806
Janjgirh Champa	1176.231	56.811
Balodabazar	993.276	40.859
Mahasamund	1128.186	47.915
Raipur	1052.954	40.953
Bemetara	1062.456	50.179
Rajnandgaon	1113.817	54.256
Durg	1127.57	53.708
Balod	1157.274	49.546
Dhamtari	1143.952	39.329
Gariyaband	1165.771	39.304
Kanker	1298.472	48.176
Kondagaon	1300.7	59.48
Narayanpur	1368.229	50.169
Bijapur	1518.279	56.024
Dantewada	1462.113	64.113
Bastar	1417.281	85.65
Sukma	1474.303	65.049

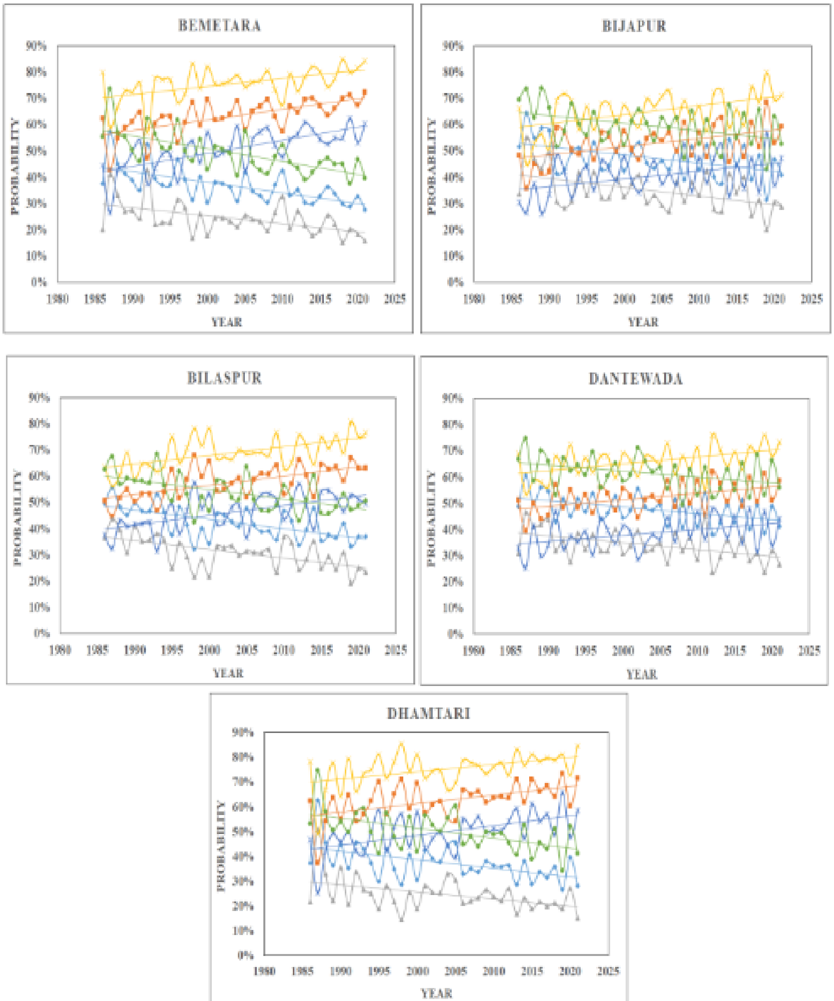
Markov-chain initial and conditional probabilities of dry and wet days

Initial probabilities in a Markov Chain model for rainy and dry days indicate how likely it is that the first day will be rainy or dry. It is common practice to make such estimates using either past data or accumulated system knowledge. However, conditional probabilities explain how likely it is that conditions will change over time (from wet to dry). Wet spells can break up into dry ones depending on the conditional probability of dry days following wet ones. These possibilities are likewise calculated from past data and may change with the specific region or environment under consideration.

Probability distribution for each district

The probability of a wet day (P(W)) initially exhibits a declining trend and is currently below 50%, while the probability of a dry day (P(D)) initially exhibits an increasing trend and has exceeded 60% for all the districts, including Balod, Baloda-bazar, Balrampur, Baster, Bemetara, Bijapur, Bilaspur, Dantewada, Dhamtari, Durg, Gariaband, JanjgirChampa, J The likelihood of a dry day (P(D)) for the remaining crop growth period constantly exceeds 60%, whereas the probability of a wet day (P(W)) varies between 30% and 50% (Fig. 3).

Taking consideration of the conditional probabilities, the likelihood of a wet day immediately following a dry day [P(W/D)] exceeds 65 to 75% the probability of a dry day immediately following a wet day ranges from 50 to 70%, and the probability of a dry day immediately following a wet day is less than 50% (Fig. 3). Furthermore, it is significant that the likelihood of having a dry day followed by another dry day [P(D/D)] is greater than 50% indicating an upward trend in districts such as Balod, Balodabazar, Balrampur, Bemetara, Bilaspur, Dhamtari, Durg, Gariaband, JanjgirChampa, Jashpur, Kabirdham, Kanker, Kondagaon, Korba, Koriya, Mahasamund, Mungeli, Narayanpur, Raigarh, Raipur, Rajnandgaon, Sukma, Surajpur, Surguja, and others. Districts such as Dantewada, Bijapur, and Bastar, on the other hand, exhibit decreasing tendencies, although having much more rainfall than the other districts listed in Table 2. In conclusion, certain measurements show a decreasing trend, while others show a growing trend. Soil moisture is critical for crop survival during dry times, and it is worth noting that rainfall accumulation is lower in districts like Balodabazar, Raipur, Kabirdham, Gariaband, and Mungeli.


BEMETARA
BIJAPUR
BILASPUR
DANTEWADA
DHAMTARI
PROBABILITY
YEAR
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025

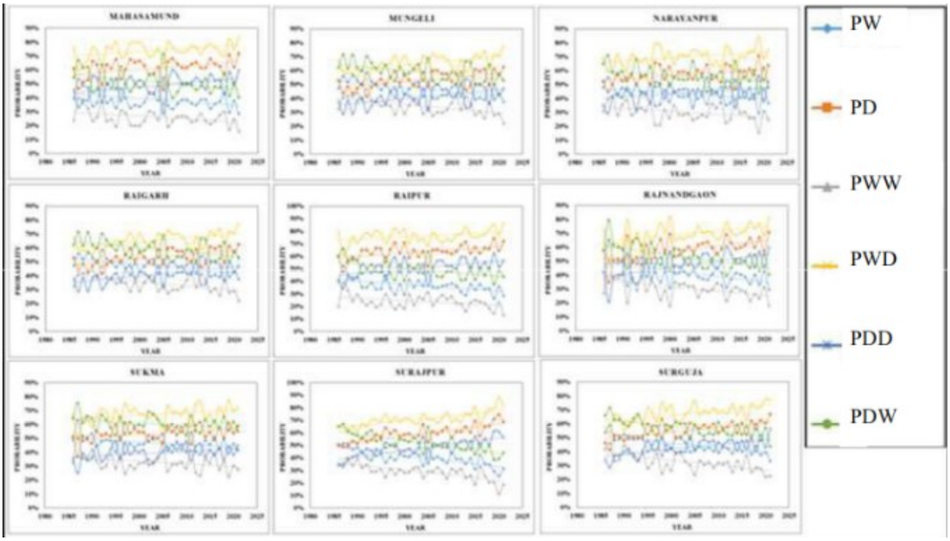


Figure 3: District-wise probability distribution

CONCLUSIONS

This work used a Markov chain technique to forecast rainfall patterns in Chhattisgarh, India, taking into account the importance of rainfall on agricultural output and water resource management. The Markov chain model captures transition probabilities between rainfall districts by analyzing past rainfall data, allowing for the prediction of future rainfall patterns and the chance of shifting between districts. The study emphasizes the necessity of knowing and forecasting dry and wet spells for optimal planning in a variety of industries. The findings add to our understanding of rainfall forecast methodologies, particularly in the context of Chhattisgarh, where rainfall patterns vary significantly across different places.

According to the study, the initial probability of a wet day is decreasing, while the probability of a dry day is increasing, by 60% in all regions. During the remaining crop growth season, the probability of a dry day continuously exceeds 60%, while the probability of a wet day is between 30% and 50%. When looking at conditional probabilities, it is worth noting that the likelihood of a wet day following a dry day reaches 65 to 75%, but the likelihood of a dry day preceding a wet day range between 50 and 70%. Furthermore, the probability of consecutive dry days is greater than 50% in certain districts, indicating an upward trend, while other districts show decreasing tendencies despite experiencing higher rainfall than other areas, indicating that the longer duration of wet spells is shifting towards the shorter duration and the shorter duration frequency is high, according to this study. Hence, the present study emphasizes the importance of soil moisture for crop survival during dry periods and identifies districts with reduced rainfall accumulation. The study emphasizes the importance of advanced statistical models, like

Markov chains, in rainfall forecasting, highlighting the necessity for proactive actions in Chhattisgarh to adapt to changing climatic circumstances and optimize resource allocation. Finally, these activities contribute to the region's long-term development and resilience.

Limitations of the present study

The Markov Chain Approach for evaluating change in rainfall patterns during dry and wet spells has limitations, including its broad time scale, sensitivity to initial conditions, and challenges in accurately modelling complex rainfall dynamics. It is more suitable for short- to medium-term projections than long-term climate predictions. Applying this method beyond Chhattisgarh requires high-quality historical data, consideration of regional climate similarities, acknowledgment of model uncertainties, and incorporation of climate change trends. Sensitivity analyses should be conducted to assess model robustness. Customizing the methodology to the specific characteristics of the target region is essential for reliable and meaningful results.

FUTURE SCOPE OF THE PRESENT STUDY

Evaluating dry and wet spells using the Markov Chain Approach in Chhattisgarh, India is crucial for understanding climate change impacts and managing water resources effectively. Insights from this research aid in developing adaptation strategies for water storage, distribution, and agriculture while informing infrastructure planning. Accurate assessments of rainfall shifts support efficient reservoir operations, groundwater replenishment, and water allocation policies to ensure a sustainable supply for agriculture, industry, and households. Collaborative efforts across climatology, hydrology, agriculture, and economics can further enhance understanding and mitigation strategies for evolving precipitation patterns in the region.

ACKNOWLEDGEMENT

The authors would like to thank the Indian National Institute of Technology, Raipur, for their kind support and for providing the opportunity for conducting the present study.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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